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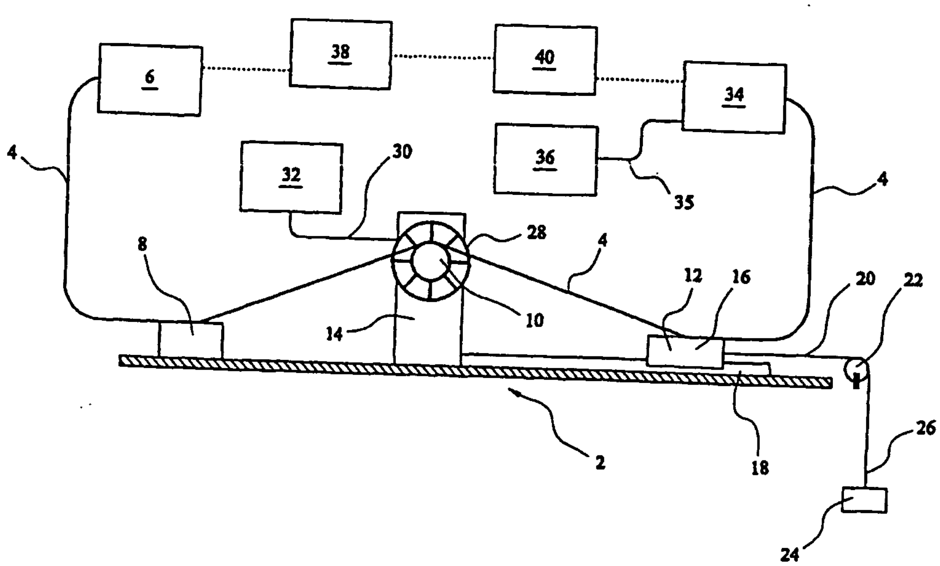
(54) Title: APPARATUS AND METHOD FOR ABRADING OPTICAL FIBRE




(57) Abstract

Apparatus for abrading an optical fibre (4) has a wheel (10) or roller having an abrasive surface. There are means (8, 12) for holding an optical fibre against the abrasive surface, a transmitter (6) operative to transmit light into the optical fibre, a receiver (34, 36) operative to detect the light transmitted through a region of the optical fibre to be abraded. In use, the receiver is operative to provide a signal dependent on the level of light received during abrasion.

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# Apparatus and Method for Abrading Optical Fibre

## Technical Field

The present invention relates to, in its various aspects, an apparatus for abrading an optical fibre, a method of abrading an optical fibre, apparatus for determining the orientation of a polarisation maintaining optical fibre, apparatus for abrading a polarisation maintaining optical fibre and a corresponding method, and a method for determining the orientation of a polarisation maintaining optical fibre.

As used in this text, the term light covers other forms of electromagnetic radiation; however, infra red and visible light in particular is contemplated.

## Background

The propagation of an optical signal through an optical fibre can be modified in a variety of ways by interacting with the evanescent field extending into the cladding region. Two options are available to access the evanescent field:

(1) reducing the fibre diameter until the evanescent field extends beyond the cladding, by perhaps heating and drawing the fibre, and

(2) removing the cladding locally by grinding and polishing.

Grinding and polishing techniques are known from "Single-mode fibre optic directional coupler"; R.A. Bergh, G. Kotler, H.J. Shaw; Electronic Letts. 1980, Vol. 16 pp260-261 involving mounting the optical fibre onto an arc slot cut into a glass substrate block. In this technique the block is held in a jig and a rotating polishing flat removes the surface material. Several drawbacks exist with

this known technique, in particular, the necessity to remove large quantities of the glass substrate block, and optimisation of the interfacing epoxies connecting the fibres to the substrate. This known technique is therefore costly and limited in flexibility for miniaturised component fabrication.

A paper describing seeking to remove material from the fibre alone is "Optical fibre polishing with a motor-driven polishing wheel"; C.D. Hussey, J.D. Minelly; Electronics Letts. 1988, Vol.24, No.13 pp805-807. This technique involves supporting the fibre over a rotating wheel, and applying grinding paste until the cladding is removed. There are many variables in this process, such as:

the diameter of the rotating grinder,

the tension of the fibre,

the speed of rotation, and

the determination of the grinding depths to define the points at which to change the grinding pastes, which would suggest this would be difficult to implement in practice.

Statements of Invention

In a first aspect, the present invention provides apparatus for abrading an optical fibre comprising a wheel or roller having an abrasive surface, means for holding an optical fibre against the abrasive surface, a transmitter operative to transmit light into the optical fibre, and a receiver operative to detect the light transmitted through a region of the optical fibre to be abraded, in which in use, the receiver is operative to provide a signal dependent on the level of light received during abrasion.

Preferably, abrasion is stopped when a predetermined level of light received is obtained.

Preferably, the optical fibre is clamped on one side and weighted on the other side of its region for abrasion so as to maintain a constant tension in the optical fibre. Preferably the rate of rotation of the wheel or roller is monitored. Preferably several steps of abrasion are undertaken, each until a predetermined level of light transmitted through the abrasion region is received.

The present invention in its first aspect also relates to a corresponding method of abrading an optical fibre.

In a second aspect, the present invention provides apparatus for determining the orientation of a polarisation maintaining optical fibre, comprising abutment means to in use apply a force transverse to the longitudinal axis of the fibre so as to bend the fibre, a transmitter for transmitting light through a region of the fibre to which, in use, the force is applied, a polariser connected to an optical detector, the polariser being rotatable in use so as to enable detection of maximum and minimum received power levels by the detector, means to rotate the fibre around its longitudinal axis so as to determine an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum detected power levels corresponding to an axis of polarisation of the fibre.

Preferred embodiments of the present invention in its second aspect have advantages over the approach of aligning a fibre from one end where mechanical twists destroy alignment and in addition many types of fibres have inherent axis twist resulting from manufacture.

The means to rotate are preferably precision rotation units.

The abutment means is preferably a removable tube attached to a wheel against which a region of the optical fibre lies.

In its second aspect, the present invention also relates to apparatus for abrading a polarisation maintaining optical fibre comprising a wheel or roller having an abrasive surface, means for holding an optical fibre against the abrasive surface, a transmitter operative to transmit electromagnetic radiation into the optical fibre, and a receiver operative to detect the electromagnetic radiation transmitted through a region of the optical fibre to be abraded, in which there is also provided abutment means to in use apply a force transverse to the longitudinal axis of the fibre so as to bend the fibre, a polariser connected to the receiver, the polariser being rotatable in use for determination of maximum and minimum transmitted power levels, means to rotate the fibre around its longitudinal axis so as to set the fibre to an orientation along an axis of polarisation before removing the abutment means and rotatable polariser and abrading by rotating the wheel by determining an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum received power levels.

The present invention in its second aspect also relates to corresponding methods.

Preferably, in use, the receiver is operative to provide a signal dependent on the level of electromagnetic radiation received during abrasion.

Preferably, abrasion is stopped when a predetermined level of electromagnetic radiation received is obtained.

In its second aspect, the present invention also relates to a method for determining the orientation of a polarisation maintaining optical fibre by applying a force transverse to the fibre axis, transmitting light through the region of the fibre to which the force is applied, and through a polariser, connected to an optical detector, rotating the polariser so as to detect maximum and minimum power levels, rotating the fibre around its longitudinal axis so as to determine an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum detected power levels corresponding to an axis of polarisation of the fibre.

In its third aspect, the present invention relates to a polariser comprising a polarisation maintaining optical fibre which has been controllably abraded to form an abraded region on one side of the fibre in one of its planes of polarisation, the abraded region being at least partially covered with a metal layer.

In its third aspect, the present invention also relates to a corresponding method of making a polariser.

The metal can be a single layer or multiple layers.

## Detailed Description of the Preferred Embodiments

Preferred embodiments of the present invention in its various aspects will now be described by way of example and with reference to the Figures, in which:

Figure 1 is a schematic diagram illustrating apparatus for optical fibre cladding removal, and

Figure 2 is a schematic diagram illustrating apparatus for optical fibre cladding removal with optical fibre polarisation alignment.

Apparatus for Grinding/Polishing

As shown in Figure 1, the apparatus 2 is for removing locally the cladding to a required depth. The optical fibre 4 is attached to the optical transmitter 6 to launch light into it. The wavelength of the transmitter is selected to ensure that the optical fibre 4 transmits with a single mode and has generally the desired operational wavelength of a component being manufactured. The fibre 4 is held by a first clamp 8 so as to be suspended over a polishing wheel 10 and supported by a second clamp 12 which is a sliding clamp located on the opposite side of the polishing wheel 10 to the fixed clamp 8. The first clamp 8 is fixed and the second clamp 12 consists of a sliding stage 16 supported on a rail 8, free to move toward or away from the wheel 10. The sliding stage 16 is attached to chain 20 which passes over a pulley 22. A weight 24 is attached to the opposite end 26 of the chain 20. By this method a constant strain is applied to the fibre 4 which is selectable by changing the weight 24. The wheel 10 has a support column 14 and the height of the wheel 10 is adjustable to alter the surface contact of the fibre 4 with the wheel 10. Wheels of different diameters are usable to vary the length of its contact surface with the fibre 4. The wheel 10 is made of glass to support the grinding and polishing medium, but in alternative embodiments can be made of other materials. Apparatus for monitoring the wheel rotation speed is incorporated, in this embodiment a segmented disc 28 is used which rotates at the same rate as the wheel 10 and intercepts an infra red beam (not shown) thereby giving a pulsed signal 30 proportional to the rotation rate. The signal is fed to a frequency counter or tachometer 32.

The light transmitted by the fibre 4 is input to an optical detector 34 which provides a voltage output signal 35 to a

voltmeter 36 proportional to the level of optical power reaching the detector.

In the preferred embodiment, a modulator 38 is provided connected to both the optical transmitter 6 and a lock-in amplifier 40. The optical detector 34 is also connected to the lock-in amplifier 40. This allows more sensitive detection of the level of optical power transmitted through the fibre 4 than in a similar but alternative embodiment (not shown) in which modulator 38 and lock-in amplifier are omitted.

Method of Grinding/Polishing

Using the preferred apparatus described above, the preferred method for removing locally the cladding of the optical fibre 4 consists of a single grinding stage and two polishing stages during which throughput optical signal levels are monitored. The steps undertaken are as follows:

The fibre 4 is placed over the wheel 10 and clamped into the clamps 8, 12 and tensioned by applying the required weight 24 to the chain 20 attached to the sliding stage 16.

The central section of the fibre 4 is marked.

The fibre 4 is removed from the wheel 10 and its outer acrylate coating stripped at the mid position of the marked section by the required amount. The fibre 4 is then cleaned with a solvent such as isopropyl alcohol.

The speed of the wheel 10 is set to a pre-defined rate.

Grinding paper or paste is attached to the wheel 10 and the fibre 4 placed on the wheel 10. A few drops of high refractive index oil are placed on the fibre 4 covering the section to be ground.

The fibre 4 is ground while monitoring the transmission signal level using voltmeter 36. The grinding process is stopped when the transmitted power has dropped by the required level. The high refractive index oil reduces the transmission of light through the ground region of the fibre 4 in proportion to the level of evanescent field intercepted, i.e. distance from the core.

The fibre 4 is removed from the wheel 10 and the wheel 10 is cleaned with isopropyl alcohol.

The ground section of the fibre 4 is also cleaned with isopropyl alcohol.

A lens polishing cloth (not shown) is placed on to the wheel 10 with a water solution of cerium oxide.

The fibre 4 is placed back on the wheel 10 and polished for a period of time, during which the throughput signal level is monitored. Once the transmitted power has reached the required level, the process is stopped.

The fibre 4 is removed and the polished section cleaned.

The process is repeated with a finer polishing particle size until the final device quality is achieved.

Of course, additional grinding and polishing stages can be undertaken to modify the where appropriate properties of the locally decladded optical fibre 4.

Alignment of Polarisation Maintaining Fibres for Grinding/Polishing

Polarisation maintaining fibres have preferential axes defined by inducing a high birefringence during fabrication. To produce a useful component by decladding a region of such a fibre requires that the precise positions of the axes are determined in the abrasion region. In other words the fibre must be aligned at the point of grinding.

The apparatus for doing this is shown in Figure 2. This apparatus is basically as shown in Figure 1. In addition two precision rotation units 42, 42 of known type are attached between the wheel 10 and the respective clamp 8, 12. In an alternative embodiment (not shown) a single precision rotation unit is used at one end only.

The fibre 4 is held in the units 42,42 such that additional birefringence is not introduced to the fibre 4 through pressure. Both rotation units 42,42 are adjusted in the same direction, thereby rotating the orientation of the fibre 4 birefringent axes relative to the surface of the wheel 10. The fibre 4 is suspended over the wheel 10 which is not rotating but to which a small diameter tube 44 is attached, so as to lie on the wheel 10 rim and with an axis

parallel to the central axis of the wheel 10. The fibre is bent over the tube 44. A weight 24 is applied to the sliding stage 16 to provide sufficient strain to the fibre

4. A constant force is applied to the fibre 4 on the tube 44, by applying a known weight 24 for example. The force of the tube on the side of the fibre 4 locally modifies the birefringence of the optical fibre 4.

Light of a wavelength such that the fibre 4 propagates a single mode in both polarisation states, is linearly polarised and transmitted through the fibre 4 such that the polarisation aligns with one of the fibre 4 axes. The light remains polarised on the single axis through the full length of fibre 4, when the fibre 4 is unperturbed by external effects. Applying the force to the side of the optical fibre 4 as described above causes light to couple to the orthogonal polarisation mode (other axis) dependent upon the magnitude of the force and the direction relative to the fibre axes. A force supplied along either axis does not couple any light whereas a force applied at 45 deg to the axes couples a maximum level of light. Between these two extremes, the level of light varies with the angle. Therefore, by detecting the level of light in the orthogonal polarisation mode at the output of the fibre the angle of the force applied to the axes is determined.

The level of light in each polarisation mode is determined by transmitting a low coherence light signal into the fibre 4. An edge emitting light emitting diode (E.L.E.D.) or superluminescent laser diode (S.L.D.) or similar device provides the low coherence light signal. The properties of the optical fibre 4 are such that the polarisation modes have different propagation constants and create a relative time delay between the propagating light in each polarisation mode. Providing the time delay is greater than the coherence time of the source then the output polarisations will no longer have a phase relationship and will add in power rather than amplitude. The output from

the fibre is passed through a polariser (not shown) of known type and the power level recorded by an optical detector 34. By rotating the polariser the maximum and minimum power levels are detected. When the difference between the maximum and minimum power levels is greatest the fibre 4 is aligned such that the force is applied along an axis. When the difference is zero, the force is at 45 degrees.

The fibre 4 is asymmetric and investigating the relative levels of power either side of the maximum difference allows the determination of the particular fast or slow axis along which the fibre 4 is aligned.

The fibre is then rotated using the rotation units until the level of coupled light is zero, at which point the fibre is clamped firmly at each end, the tube 44 is removed and the grinding procedure as described above followed involving rotating the wheel 10.

<u>Aligned Polarisation maintaining Fibre Polariser</u>

By maximising the difference in power level as the fibre is aligned on an axis (either its fast or its slow axis) and then after removal of the tube ground and polished to the required finish. Thereafter, by placing a metal layer (not shown) onto the fibre 4 a high attenuation is achieved in one polarisation mode and a very low attenuation in the orthogonal mode, thereby creating a polariser. A single or multi-metal layer such as aluminium, nickel etc. can be applied through standard processes such as evaporation to a depth greater than the skin depth for the optical

lightwave, such that the metal thickness is effectively infinite to the propagating wave of light.

CLAIMS:

1. Apparatus for abrading an optical fibre (4) comprising a wheel (10) or roller having an abrasive surface, means (8, 12) for holding an optical fibre against the abrasive surface, a transmitter (6) operative to transmit light into the optical fibre, and a receiver (34, 36) operative to detect the light transmitted through a region of the optical fibre to be abraded, in which in use, the receiver is operative to provide a signal dependent on the level of light received during abrasion.

2. Apparatus according to claim 1 comprising means to stop the abrasion when a predetermined level of light received is obtained.

3. Apparatus according to claim 1 or claim 2, in which the means for holding is operative such that the optical fibre is clamped on one side and weighted on the other side of its region for abrasion so as to maintain a constant tension in the optical fibre.

4. Apparatus according to any preceding claim, in which in use the rate of rotation of the wheel (10) or roller is monitored.

5. Apparatus according to any preceding claim, in which in use several steps of abrasion are undertaken, each until a predetermined level of light transmitted through the abrasion region is detected.

6. A method of abrading an optical fibre (4) using a wheel (10) or roller having an abrasive surface comprising holding the optical fibre against the abrasive surface, transmitting light into the optical fibre, detecting the

light transmitted through a region of the optical fibre to be abraded to provide a signal dependent on the level of light detected during abrasion.

7. A method of abrading an optical fibre according to claim 6 in which abrasion is stopped when a predetermined level of light received is obtained.

8. Apparatus for determining the orientation of a polarisation maintaining optical fibre, comprising abutment means (44) to in use apply a force transverse to the longitudinal axis of the fibre so as to bend the fibre, a transmitter (6) for transmitting light through a region of the fibre to which, in use, the force is applied, a polariser connected to an optical detector (34), the polariser being rotatable in use so as to enable detection of maximum and minimum received power levels by the detector, means (42, 42) to rotate the fibre around its longitudinal axis so as to determine an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum detected power levels corresponding to an axis of polarisation of the fibre.

9. Apparatus according to claim 8, in which the means (42,42) to rotate are precision rotation units.

10. Apparatus according to claim 8 or 9, in which the abutment means is a removable tube (44) attached to a wheel (10) against which a region of the optical fibre lies.

11. A method for determining the orientation of a polarisation maintaining optical fibre (4) by applying a force transverse to the fibre axis, transmitting light through the region of the fibre to which the force is applied, and through a polariser, connected to an optical

detector (34), rotating the polariser so as to detect maximum and minimum power levels, rotating the fibre around its longitudinal axis so as to determine an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum detected power levels corresponding to an axis of polarisation of the fibre.

12. Apparatus for abrading a polarisation maintaining optical fibre comprising a wheel (10) or roller having an abrasive surface, means (8, 12) for holding an optical fibre against the abrasive surface, a transmitter (6) operative to transmit electromagnetic radiation into the optical fibre, and a receiver (34, 36) operative to detect the electromagnetic radiation transmitted through a region of the optical fibre to be abraded, in which there is also provided abutment means (44) to in use apply a force transverse to the longitudinal axis of the fibre so as to bend the fibre, a polariser connected to the receiver, the polariser being rotatable in use for determination of maximum and minimum transmitted power levels, means (42, 42) to rotate the fibre around its longitudinal axis so as to set the fibre to an orientation along an axis of polarisation before removing the abutment means and rotatable polariser and abrading by rotating the wheel (10) by determining an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum received power levels.

13. Apparatus according to claim 12, in which in use, the receiver (34, 36) is operative to provide a signal (35) dependent on the level of electromagnetic radiation received during abrasion.

14. Apparatus according to claim 12 or claim 13, in which

in use abrasion is stopped when a predetermined level of electromagnetic radiation received is obtained.

15. A method of abrading a polarisation maintaining optical fibre using a wheel (10) or roller having an abrasive surface, by holding the optical fibre against the abrasive surface, using a transmitter (6) to transmit electromagnetic radiation into the optical fibre, and a receiver (34, 36) to detect the electromagnetic radiation transmitted through a region of the optical fibre to be abraded, providing abutment means (44) to in use apply a force transverse to the longitudinal axis of the fibre so as to bend the fibre, providing a polariser connected to the receiver, rotating the polariser to determine maximum and minimum transmitted power levels, rotating the fibre around its longitudinal axis so as to set the fibre to an orientation along an axis of polarisation before removing the abutment means (44) and rotatable polariser, and abrading by rotating the wheel (10) by determining an orientation of the fibre giving an at least substantially maximised difference between maximum and minimum received power levels.

16. A polariser comprising a polarisation maintaining optical fibre which has been controllably abraded to form an abraded region on one side of the fibre in one of its planes of polarisation, the abraded region being at least partially covered with a metal layer.

17. A polariser according to claim 16, in which the metal layer is a single layer.

18. A polariser according to claim 16, in which the metal layer comprises a plurality of layers.

19. A method of making a polariser by controllably abrading a polarisation maintaining optical fibre to form an abraded region on one side of the fibre in one of its planes of polarisation, and at least partially covering the abraded region with a metal layer.

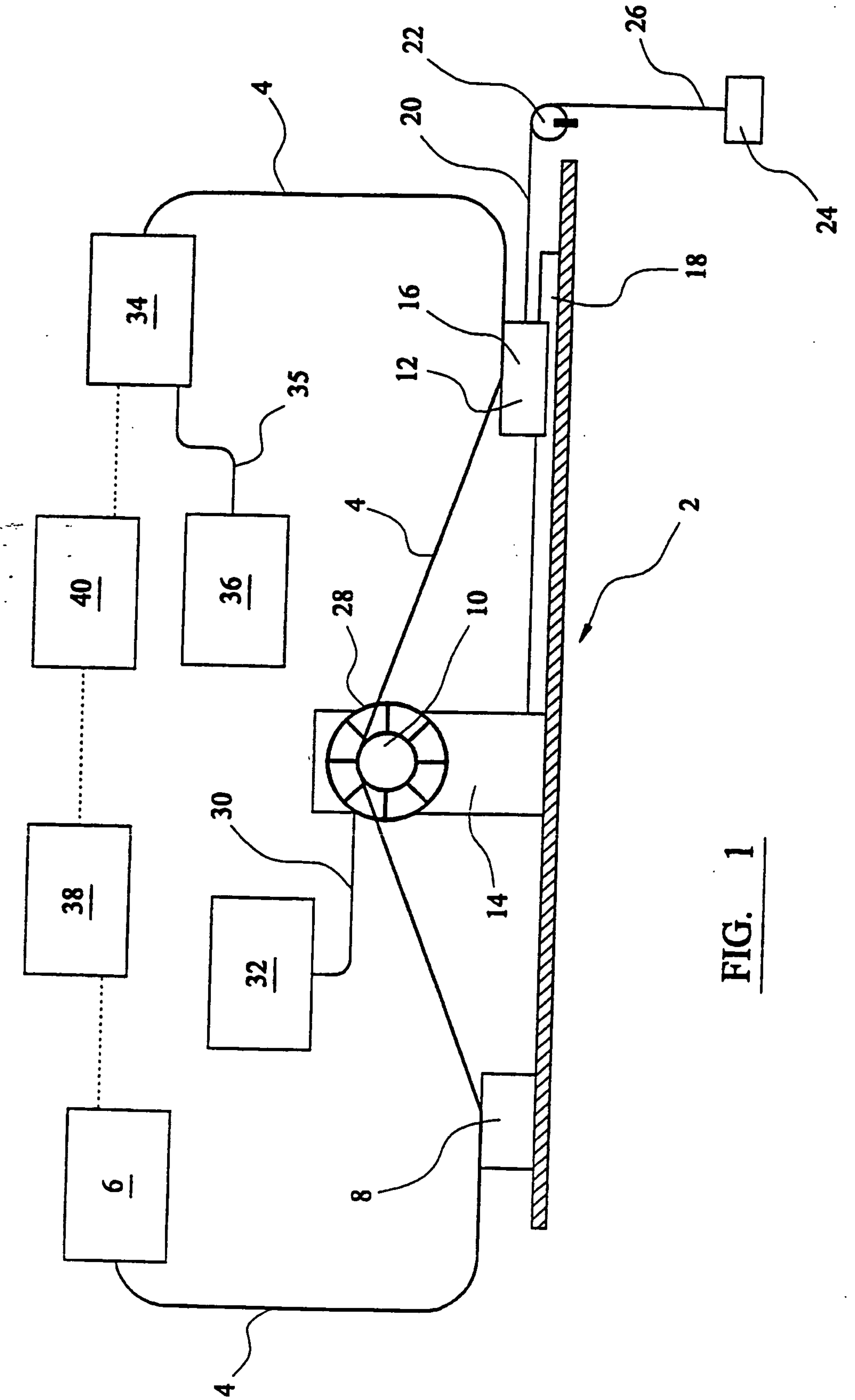


FIG. 1

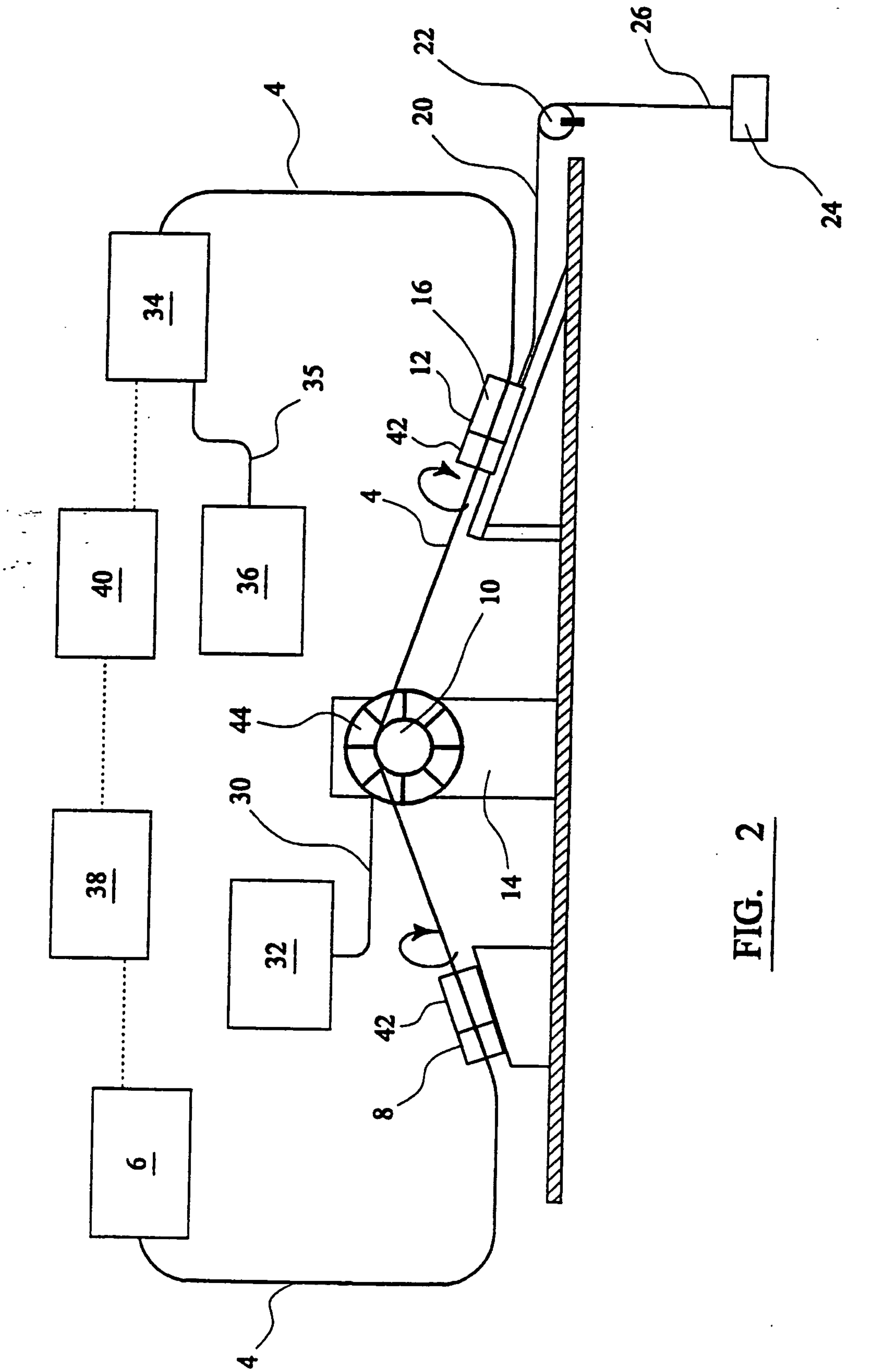


FIG. 2

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00575

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02B6/28 G01M11/00 B24B19/22

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B B29B G01M B24B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | "OPTICAL FIBRE POLISHING WITH A MOTOR-DRIVEN POLISHING WHEEL" ELECTRONICS LETTERS,GB,IEE STEVENAGE, vol. 24, no. 13, 23 June 1988 (1988-06-23), pages 805-807, XP000030130 ISSN: 0013-5194 cited in the application | 1,2,5-7 |
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search
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Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/GB 00/00575

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication,where appropriate, of the relevant passages | Relevant to claim No. |
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| X | CORDARO M H ET AL: "PRECISION FABRICATION OF D-SHAPED SINGLE-MODE OPTICAL FIBERS BY IN SITU MONITORING"<br>JOURNAL OF LIGHTWAVE TECHNOLOGY,US,IEEE. NEW YORK,<br>vol. 12, no. 9,<br>1 September 1994 (1994-09-01), pages 1524-1531, XP000484331<br>ISSN: 0733-8724<br>chapter III B | 1,2,5-7 |
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